UNIVERSITY OF PENNSYLVANIA

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A DISSERTATION

IN BOTANY

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

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Reprint from
Plant Physiology, Vol. 12 No. 1

PHILADELPHIA
1936

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Reprinted from PLANT PHYSIOLOGY, 12: 117–133, 1937.

EFFECTS OF X-RAYS ON *ZEA MAYS*

MARY A. RUSSELL

(WITH EIGHT FIGURES)

Introduction

Since the discovery of x-rays, their effects on both plants and animals have been studied as important biological problems. Many reports of early work are conflicting because quantitative results have been possible only in recent years, after methods of accurately measuring the dosage were perfected.

In the study of many general problems, plants are ideal material because of the large numbers which can be used and the ease with which environmental conditions can be modified or kept constant as occasion demands. Samples can be taken for cytological studies as the experiment progresses without detracting from the final results. Numerous reports on plant experiments have come from hospital laboratories where the work has been done with the conviction that many of the results will be applicable to problems of animal x-ray technique.

The work reported here was started for the purpose of finding out how *Zea mays* would react to x-ray treatment in various aspects of its growth and appearance, in order to use it eventually as a test material for studying effects of irradiation as they might be influenced by changing environmental conditions. *Zea mays* has been used occasionally for special radiation problems. STADLER (**14**) found it valuable for studies of mutations produced by x-rays because its genes had been more thoroughly mapped than those of many other plants. BERSA (**2**) reported *Zea mays* to be relatively more resistant to irradiation than many plants which he tested. He used it extensively for cytological examination of irradiated root tips.

Materials and methods

The source of radiation was a standard air-cooled Coolidge tube. A constant potential of 180 kv. was used and the filament current was maintained at 3.7 ma. The distance from the center of the target to the material to be irradiated was 30 cm. The only filters were the heavy pyrex glass of the tube and the paper over the seedlings. The actual strength of the x-rays used was measured during radiation by the usual ionization-galvanometer arrangement, the ionization chamber having been calibrated previously with a standard chamber as described by TAYLOR and SINGER (**17**). The calibration of the apparatus gave a factor of 1.7 r units per centimeter of deflection of the galvanometer. Thus at a deflection of 15 cm. for 40 minutes, the dose

would be $1.7 \times 15 \times 40$ or 1020 r. The ROENTGEN unit or "r" was defined at the Second International Congress of Radiology in 1928 as follows: "... the quantity of radiation which, when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in one cubic cm. of atmospheric air at 0° C. and 76 cm. mercury pressure such a degree of conductivity that one electrostatic unit of charge is measured at saturation current" (**16**).

Improved Golden Dent field corn was used in all experiments. The dry grains were planted between layers of moist paper toweling in glass chambers placed in a dark incubator at 24° C. After 72 hours most of the primary roots were slightly more than 1 cm. long. The grain was always placed in the germinating chamber in the evening at about the same hour in order to avoid differences in sensitivity due to possible natural mitotic rhythm. These precautions were also for the purpose of obtaining an equal degree of hydration in all experiments.

Seedlings were selected which had fairly straight roots 10 to 15 mm. long. A spot of India ink was placed exactly 10 mm. from the tip of each root and all future measurements were made from this point. In most experiments 20 seedlings were used in each group. The plants to be treated were individually placed on damp filter paper over the bottoms of glass dishes. The side of the grain where the shoot was about to emerge was always placed up in order that all of the embryos might be equally exposed to the x-rays. The dishes were closely covered with three layers of moist Scott Tissue toweling to prevent evaporation from the seedlings during radiation. The controls were kept under the same conditions outside of the x-ray apparatus.

Immediately after treatment the seedlings were placed either in pots of damp earth for observation in the greenhouse or in jars of loosely packed sphagnum to be put into the incubators for root study. The irradiated plants grown in soil had the normal greenhouse conditions of light and temperature. A large number of pots were prepared at one time with the same lot of soil to insure uniformity of nutrition.

Results

EFFECT OF X-RAYS ON AERIAL PARTS OF *ZEA MAYS*

The following observations were made on a typical series raised in the greenhouse. Groups of 12 seedlings each received doses varying from 100 to 5000 r. Up to the fifth day there was no difference in the heights of the shoots of the different groups, but on the fourth day close inspection showed that there was a delay in the bursting of the sheath or coleoptile in the heavily irradiated plants. The number in each group with the shoots visible at this time was as follows: controls, 11; 100 r, 7; 200 r, 8; 1200 r, 1; 1600 r and above, 0. On the sixth day all of the controls, 100, and 200 r groups had

burst the sheath as had also about 50 per cent. of the plants of the more heavily irradiated groups.

Measurements made 8 days after irradiation showed that all growth of the sheath had stopped both in the control and in all of the treated groups. The following figures indicate that the net growth of the sheath was not retarded by irradiation: average height of control, 22 mm.; irradiated with 800 r, 25 mm.; and 2000 r, 23 mm.

From the sixth day, the growth in height of the plants receiving doses of 1200 r and higher fell behind that of the controls. The upper limit of the amount of radiation which allows the majority of seedlings to unfold the first leaf was about 1200 r. When a dose of 800 r was applied, the growth rate during the first month was equal to that of the controls when only the height of the shoots was considered. When part of this 800 r group was removed from the soil and measurements made 12 days after irradiation, the roots had an average length of 207 mm. as compared with 238 mm. for the controls. After three months the tops of the remainder of the 800 r group were about two-thirds of the height of the controls. This may mean that in the case of the shoots there was a very long latent period before the effects of irradiation could be observed. On the other hand, it is possible that this later dwarfing was caused by lack of root development owing to x-ray injury, rather than a direct effect of irradiation on the tops themselves. After a dose of 1200 r, most of the seedlings died in two weeks, having grown little more than the group which received 2000 r, while the survivors, a quarter of the whole number, grew as well as the plants in the 800 r groups. At a dose of 1200 r the individual sensitivity seemed most apparent. The individuals in the groups receiving doses between 1400 and 5000 r showed little variation, either in length of roots, which averaged 54 mm. at death, or in height of shoots, which averaged 45 mm. at that time.

The leaves of plants which received a dose of 200 r and more showed many small areas of yellowish green between patches of normal color. Up to 400 r, the first three leaves were the only ones showing this chlorotic disturbance. With higher doses, which still allowed fairly normal growth of tops, a much longer time elapsed before normally colored leaves were produced. With very high doses the occasional plants which were able to produce one leaf, were decidedly yellow with very small areas of normal green color.

Leaves in the 800 r group, which were of normal length, showed a peculiar twisting and curling in some cases. The edges of the leaf were slightly inrolled and tended to move toward the under side. This condition persisted throughout the three months of the experiment.

Special root studies

The seedlings grown in sphagnum were used for observations of the behavior of roots after irradiation. Tests showed that the plants could be

carefully removed from the jars twice a day without affecting the rate of growth. It can be seen from table I that the final length attained by roots

TABLE I

ROOT LENGTH ATTAINED IN SPHAGNUM AFTER KILLING DOSES OF X-RAYS

TEMPERATURE	DOSE IN R UNITS	HOURS AFTER TREATMENT	AV. LENGTH
°C.		hr.	mm.
22	10,000	77	32
"	7,000	77	28
"	5,000	77	31
"	5,000	63	34
"	4,000	63	31
"	3,000	60	43
29	3,000	50	41
24	2,500	68	53
17–21	2,000	134	51
22	2,000	90	52
24	2,000	70	50
24	2,000	94	62
24	2,000	85	51
29	2,000	40	52
35	2,000	45	44
36	2,000	42	47
36	2,000	43	41

after receiving doses of 4000 to 10,000 r shows great uniformity. The growth curves are also practically identical throughout this range. A dose of 4000 r would then appear to be near the limit beyond which further irradiation could be expected to have no observable effect, at least under these experimental conditions. As the dose is reduced below 4000 r there is a fairly regular increase in the rate of growth of the primary root after irradiation. Doses below 150 r produce no measurable differences between such treated seedlings and their controls when primary roots alone are tested.

A study was made to determine the smallest dose that would consistently produce a measurable difference between such treated seedlings and their controls. Preliminary observations showed that the rootlets growing laterally from the primary roots are the parts of the plant which first exhibit visible evidence of x-ray injury, although these rootlets cannot be seen at the time of irradiation. It has been found (table III) that, in all experiments at a given temperature, the time required for lateral roots to appear on normal seedling is remarkably constant. Table II shows that the time between irradiation and the first appearance of lateral roots steadily increases with the dose from 75 to 1500 r, which is near the upper limit of the amount

TABLE II

TIME OF APPEARANCE AND POSITION OF LATERAL ROOTS WHEN GROWN AT 24° C. AFTER X-RAY TREATMENT

DOSE IN R UNITS	APPEARANCE IN AT LEAST 33% OF CASES			AV. LENGTH OF PRIMARY ROOT	AV. DISTANCE OF FIRST ROOTLET FROM SEED
I	TREATED	CONTROLS	DIFFERENCE	V	VI
	II	III	IV		
	hr.	*hr.*		*mm.*	*mm.*
60	61	61	0	94	0
75	84	68	16	116	0
150	93	68	25	103	0
300	100	68	32	113	.....
300	87	63	24	122	6
600	94	67	27	98	.....
600	96	67	29	110	13
1,000	90	64	26	90	.....
1,000	114	63	51	65	25
1,000	160	68	92	98	20
1,500	160	67	93	65	31
1,500	160	68	92	73	20

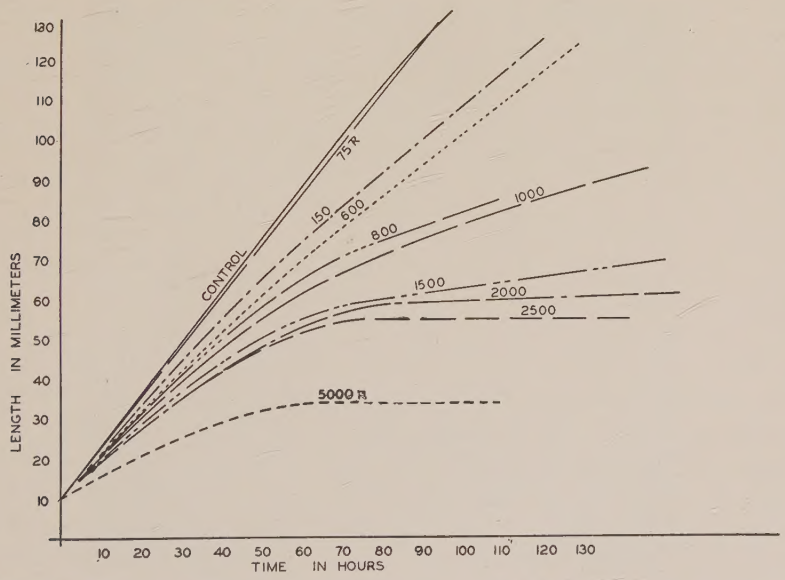

FIG. 1. Effect of various doses of x-ray on growth of primary roots of *Zea mays* in sphagnum at 24° C.

of irradiation that allows a few lateral roots to be formed on most of the seedlings.

Figure 1 shows that the growth rate of the primary roots treated with 75 r was identical with that of the controls, but the lateral roots in this irradiated group appeared 16 hours later than those of the controls. It has been stated above that 150 r was the smallest dose that could be depended upon to check the growth of the primary root in most of the corn seedlings.

Control seedlings grew at an increasing rate as the temperature was raised from 17° to 36° C. In these plants the lateral roots tended to emerge when the primary root was about 100 mm. long, irrespective of the time required to reach that length at various temperatures. Table III shows that

TABLE III

TIME OF APPEARANCE OF ROOTLETS ON CONTROLS AT DIFFERENT TEMPERATURES

TEMPERATURE	TIME OF APPEARANCE OF ROOTLETS		AV. LENGTH OF MAIN ROOTS	
°C.	hr.	hr. (mean)	mm.	mm. (mean)
37–39	39	39	112	112
36	38		106	
36	36	37	82	94
35	44		73	
35	40		129	
35	36	40	115	104
29	40		95	
29	36		91	
29	43		104	
29	39		108	
29	47		104	
29	45	42	96	98
24	63		90	
24	68		99	
24	67	66	119	103
22–24	96		122	
22	97	96.5	122	122

with increasing temperatures the time required for the appearance of lateral roots decreases, while the length of the primary root at this time is very constant. For instance, in a group raised at 22° C., after the usual germination period at 24° C., the lateral roots appeared 97 hours after the first measurement. In another group raised at 35° C. the rootlets appeared after 48 hours, the average length of the primary roots being the same in each case. Figure 2 shows the very regular rate of decrease in time necessary for the appearance of rootlets as the temperature increases.

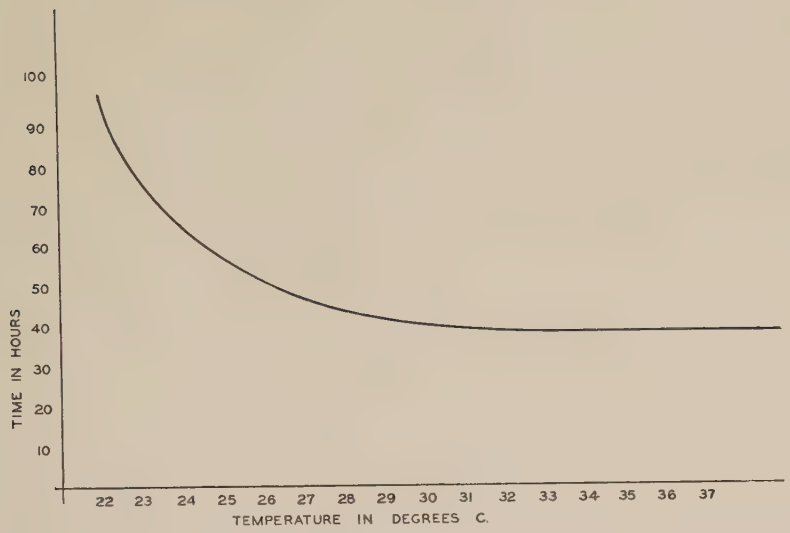

FIG. 2. Effect of increase in temperature on time required for appearance of secondary roots on seedlings of *Zea mays*.

Careful examination of the control seedlings showed that the rootlets first appeared on the primary root immediately below the grain in all cases, no matter how long their appearance was delayed by cold and the slow growth

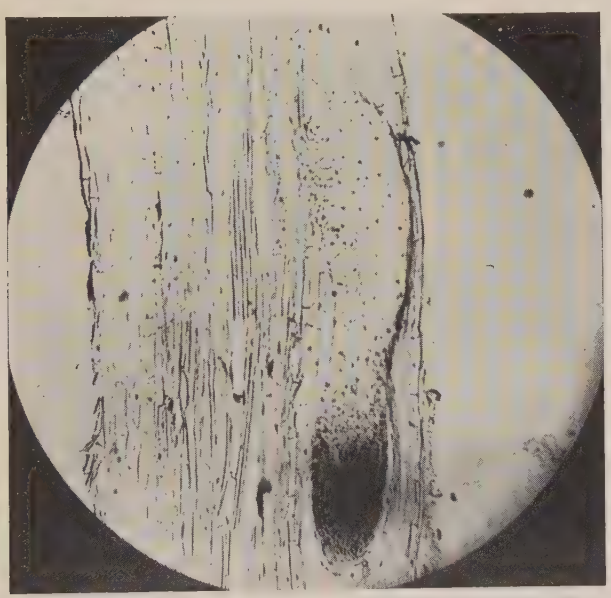

FIG. 3. Section showing abnormal growth of secondary root after an x-ray dose of 1500 r.

accompanying it. It can be seen from column VI of table II that, when doses of 300 r and more were used, the average distance of the first lateral root from the grain increased from 6 mm. to 31 mm. after a dose of 1500 r. The roots grown in soil showed this same type of behavior after irradiation. With the higher doses the primary root had only a tassel of rootlets very close to its tip. Histological sections made from roots which had received a dose of 1500 r showed primordia of lateral roots in the region just above the level where rootlets were growing out in a normal manner. In some cases these primordial rootlets were subnormal in size and in a few examples they had turned either up or down, growing parallel to the longitudinal axis of the primary root, and they were entirely inclosed within its tissue. Figure 3 illustrates this condition.

Effect of temperature on growth after x-ray treatment

Experiments performed to test the effect produced by keeping the corn seedlings at 6° C. during irradiation with doses of 200 to 1000 r and then allowing them to grow at 24° C. showed no differences between such treated seedlings and those similarly irradiated at room temperature. Following the failure to produce differences in sensitivity to x-radiation by means of low temperature during treatment, a number of tests were made to find out whether varying the temperature after x-ray treatment would affect the amount of injury due to irradiation. Since corn was found to thrive at temperatures of 17° to 36° C., it was possible to observe the behavior of roots whose growth rates varied widely according to the temperature selected. In the first experiment three groups of seedlings were irradiated at the same time with 2000 r, and then the separate lots were placed, with their controls, in three incubators at varying temperatures. Care was taken to measure the growth at very frequent intervals. Figure 4 shows the curves made by the

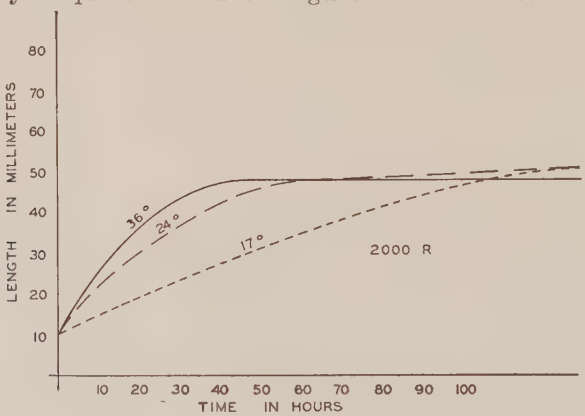

Fig. 4. Curves of growth at three temperatures after equal amounts of radiation. Length of life increases as temperature decreases.

growth of the primary roots of these seedlings exposed to 36°, 24°, and 17–21° C. after all were irradiated under exactly the same conditions. The shape of the curves is very significant, showing that the time of death was

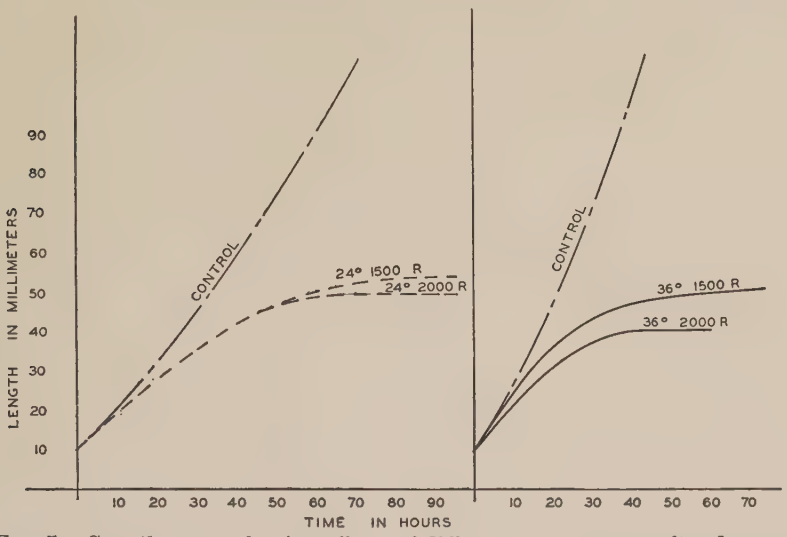

FIG. 5. Growth curves showing effects of different temperatures after doses of 1500 and 2000 r. Increasing doses decrease the latent period and the effect is exaggerated by increase in temperature.

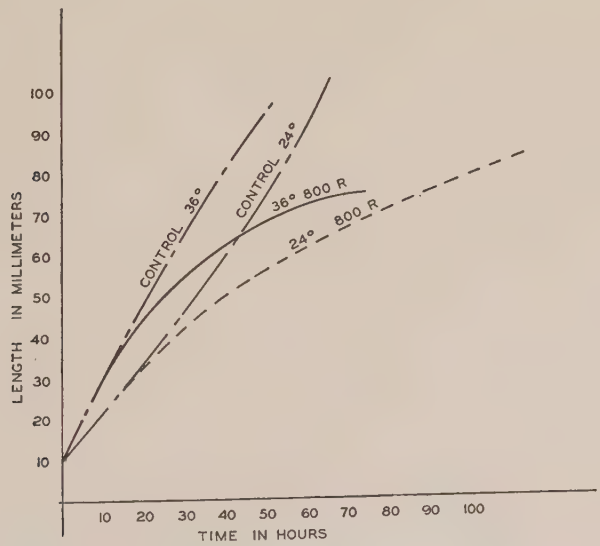

FIG. 6. Growth curves of primary roots of *Zea mays* showing effect of exposure to 24° and 36° C. after a dose of 800 r. At 20 hours the irradiated group at 24° C. shows no injury while at 36° C. roots are 4 mm. shorter than their controls.

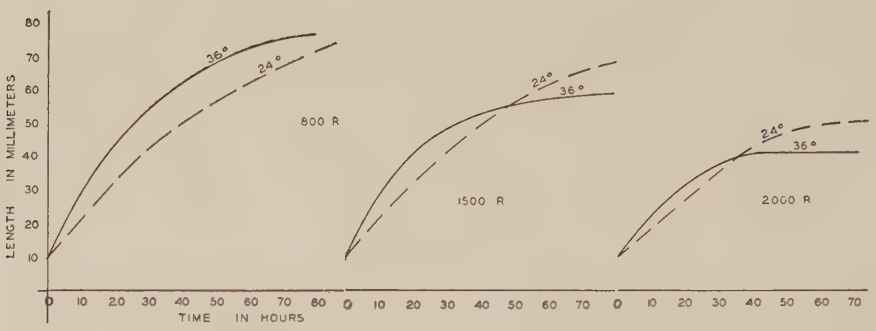

FIG. 7. Curves showing comparative effects of exposure to 24° and 36° C. after exposure to various doses of x-rays.

delayed as the temperature decreased. Similar experiments were performed by repeating the dose of 2000 r and also using 1500 and 800 r, in each case exposing part of the irradiated group to 24° and part to 36° C. with their respective controls at each temperature. Figure 5 shows that after both the 1500 and 2000 r treatments, the roots grown at 24° lived longer than those in the group at 36° C. Growth after 1500 r extends over a longer period of time at the lower temperature, and, also, the roots reach a considerably greater length before death when grown at 24° than at 36° C. Figure 6 shows that when the dose is lowered to 800 r, the irradiated groups grown at

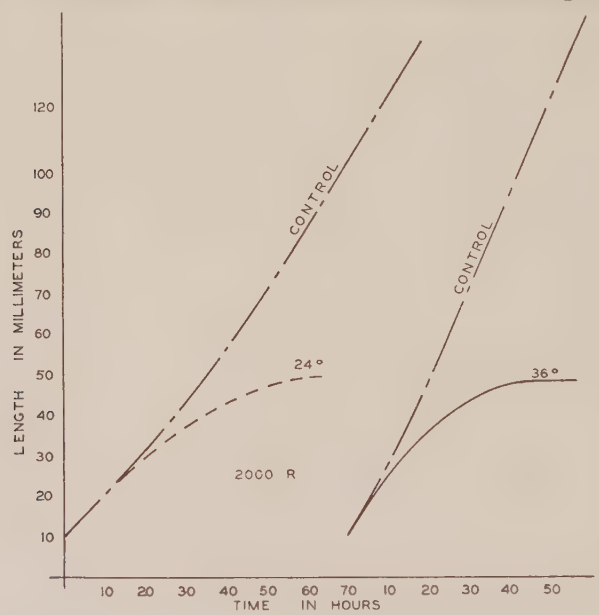

FIG. 8. Growth curves showing effect of temperature on length of latent period after an x-ray dose of 2000 r.

the two temperatures grow roughly parallel to each other, the 36° group growing the faster just as the 36° controls grow faster than the 24° controls. In figure 7 the curves of the growth following the three doses have been rearranged to show more graphically the effect of the two temperatures on each. The curves in figures 4, 5, 6, and 8 show that with all the doses used, the latent period was longer at the lower temperature. As the dose increases, the difference between the temperature effects is increased.

Discussion

The coleoptile was the only part of the corn seedling which failed to show any effects of irradiation. CATTELL (**3**) reported it to be the least sensitive part of wheat, as after a dose of 1200 r the coleoptiles showed a reduction of 8 per cent. in height while the primary roots were reduced to 45 per cent. of the length of the controls. It would appear that the coleoptile of corn is less sensitive to irradiation than the coleoptile of wheat. The apparent lack of sensitivity to x-rays of this organ may be partly explained by the results of cytological studies of *Zea mays* by TETLEY and PRIESTLEY (**18**). They found that cell division stops in the coleoptile earlier than in any other part of the embryo. The fact that cell division has probably ceased long before exposure to x-rays may account for this organ showing no injury after doses which seriously interfere with the growth of parts of the seedling in which there has been rapid cell division at the time of irradiation.

SKOOG (**13**), using moving pictures to study the behavior of the coleoptile in *Avena*, found that its growth stopped when it was ruptured by the shoot pushing through it. If it is natural for the growth to continue only as long as the sheath is intact, and if the rupture is delayed when the shoot is stunted by irradiation, then this tendency towards excess growth in height may mask the effect of x-ray treatment on the corn coleoptile. The fact that the coleoptiles of treated corn seedlings were a trifle longer than those of the controls may indicate that the stunting effect of x-rays was a bit less influential than the opposite tendency towards increased growth.

The chlorotic disturbance noted in the corn leaves is typical of the results reported for many species. NOGUCHI (**10**) examined sections of leaves from irradiated seedlings of *Helianthus annuus* and found that the light color was due both to a reduction in the number of chloroplasts and a deficiency in their chlorophyll content.

The fact that irradiation in any amount between 4000 to 10,000 r failed to produce more stunting of the primary root than did 4000 r, shows that corn responds to x-rays in this respect in very much the same manner as does wheat. FRANCIS (**5**) reported that doses increasing from 3390 to 13,000 r fail to produce any increase in damage to the seedlings either in affecting the growth or in reducing the rate of respiration. Many workers have tried in vain to find a dose of x-rays strong enough to kill the plant immediately.

In an early experiment, where it was necessary to compare the effects of irradiation on two groups of seedlings which had been treated under different conditions, the time for comparison was chosen when both groups had lateral roots starting but those of one set were further developed than those of the other. Quantitative measurements were made at first by carefully cutting off the rootlets, obtaining the dry weights of those of the two groups, and then computing the average weight of the lateral roots of each group. This laborious method was discarded when further study showed that small differences in the amount of damage caused by irradiation could be measured both by noting the time at which lateral roots appeared and also by recording the distance below the grain at which the first rootlets appeared. The use of the time factor is the more exact of the two methods. It is necessary to decide on a given proportion, such as one-third, of the plants to be required to show rootlets before the time of appearance is recorded. This helps to prevent mistakes being made when the group contains one or more freak plants which, for some unknown reason, are unusually resistant. Such individuals have been omitted in computing averages when they were few in number and extremely different from most of the group.

When preliminary experiments have been carried out at the same temperature and near the dose to be used, the time interval during which very frequent observations are necessary to establish the time of appearance of rootlets can be fairly accurately predicted. In order to compare the sensitivity of two groups of corn seedlings, a dose of 300 r would have the advantage of yielding data both on the time of appearance and the spacing of lateral roots below the grain, and it would furnish this information in a shorter time than would be required for the same observations after higher doses. Wigoder and Patten (19) observed that lateral roots of *Vicia faba* were delayed in the time of their appearance and were formed more and more distally from the seed as the dose of x-rays was increased. It is therefore possible that this type of reaction could be expected in many kinds of plants and could be used as a general method for comparing sensitivity to irradiation between groups of the same species.

The fact that the appearance of the first lateral roots is delayed by irradiation might indicate that time is required for the repair of certain damage before these roots can be formed in a normal way. The few sections which were prepared from seedlings which had been irradiated with 1500 r showed no indications of lateral roots being formed in the region just below the seed, while in the region further down there were abortive attempts at lateral root formation followed by a region producing apparently normal rootlets. Since irradiation is generally considered to have an aging effect on tissues, the failure of the lateral roots to reach the exterior along the upper part of the root might be due to the same type of conditions which prevent secondary

root formation in old, tough roots. Further study may determine whether the rootlets in the x-rayed material changed the direction of their growth because of the mechanical difficulty of penetrating the outer layers of the primary root.

In normal seedlings there was a quite definite relation between the length of the primary roots and the time of appearance of lateral roots, but this relationship was upset in the irradiated groups. Here the rootlets tended to appear while the primary root was relatively shorter, but if the plant's main root never reached a length of 60–70 mm. it was unlikely that any rootlets would be formed. It may be possible that as the plant begins to suffer from the slow growth of the x-rayed primary root, the lateral roots tend to appear earlier in proportion to the length of the main root as an attempt at compensation for the lack of absorbing power of the main root. JOHNSON (**7**) reported that irradiated seedlings of *Helianthus annuus* lack ability to absorb as much water as their controls. This condition is all the more serious for the plant, because the aerial parts, not being stunted by irradiation to the same extent as the roots, are in need of a supply of water approaching that of a normal plant.

There are reports of several experiments on the effect of irradiating living material at low temperatures. CRABTREE and CRAMER (**4**) treated mouse tumor with radium at 0° C. and found that its sensitivity to irradiation was greater than when it was treated at room temperature. MOTTRAM (**9**) obtained similar results, using *Vicia faba* (a very small number of plants) treated with both radium and x-rays. On the other hand, HENSHAW and FRANCIS (**6**) failed to find any difference in the sensitivity of wheat seedlings when irradiated at different temperatures. The same type of experiment was tried in this laboratory with corn, with the idea that this plant, being more sensitive to cold than wheat, might give somewhat different results. The findings were negative.

It was found that growing corn seedlings at different temperatures following irradiation produced differences in the length of the latent period, the ones grown at the higher temperature showing the damaging effects sooner than those which were allowed to grow more slowly at the lower temperature. This held true for groups of roots which had received a dose of 800 r and grew in a manner very nearly like the normal. The effect on the latent period became more and more noticeable as the dose was increased to 2000 r. It would be of interest to test higher doses to determine whether a stage could be reached where the damage done by irradiation would be so great that a comparatively low temperature could have no effect towards lessening the amount of injury.

With all biological material the time required for the effects of irradiation to appear varies according to the dosage, the type of organism, and probably

many other factors. It is generally considered that biological changes are the result of chemical changes set in motion by ionization during the actual time of irradiation. Conditions which would speed up or modify the chemical reactions could be expected to shorten the latent period required for the results of the biological changes to appear. Heat increases the speed of most chemical reactions and does appear to shorten the latent period in the experiments reported here.

Although irradiated seedlings grown at 36° C. begin to show the effects of irradiation at an early age, they grow fairly rapidly until they suddenly die. When groups of irradiated plants grown at successively lower temperatures are compared, it appears that the slower the plants grow, the longer they are likely to live. However, the dose of 2000 r has set a limit, perhaps within a range of 6 mm., to the amount of growth possible following that amount of irradiation. The seedlings grown at each temperature group die when their primary roots have reached this limit no matter how long a time is required for each group to grow roots of that length. This limit may be determined by any one of several factors or a combination of them. A given amount of food material may be available for the building of new root tissue and irradiation may prevent the formation or transportation of more of that substance after the original supply is exhausted. If the root is growing rapidly, it will use up its supply and die sooner than a slow-growing root which uses up its food more slowly. This theory might help explain why the primary root can grow to the same length, when either 4000 or 10,000 r have been applied. If there is the same amount of food material available originally for both groups of roots, the 4000 r dose is just as effective as the 10,000 r dose in preventing any further growth after the original supply is exhausted. As the dose was reduced below 4000 r this food formation was apparently less and less disturbed. Since growth of the plant as a whole proceeds quite normally after a dose of 800 r, it may be assumed that there is early recovery if this amount of irradiation interferes with the food supply.

Another cause of death may be the accumulation of mildly toxic substances until they interfere with natural physiologic processes, or, as Schwartz (**12**) suggests, the proteins may be giving rise to increasingly toxic products as their decomposition proceeds. Either of these conditions would be aggravated and cause earlier death with increase in temperature and the higher rate of metabolism accompanying it. The difference between the length of the latent period at different temperatures in the case of plants receiving 800 r, might be due to the difference in the rate at which toxic materials were formed. It is possible that some of these poisonous substances may diffuse out; this would help explain part of the recovery which takes place when the doses of radiation are not too heavy.

The comparative lack of irradiation injury shown in the early stages by plants grown at 24° C. and below might be due to the time element of delay

made possible by the use of lower temperatures. Several authors have tested the effect of allowing time to elapse between irradiation and the beginning of growth processes following it. STRANGEWAYS and FELL (**15**) reported that when chick embryos were kept in the refrigerator for 24 hours after irradiation and then allowed to grow in incubators at their normal temperature, the injury due to irradiation was less than the injury suffered by embryos similarly irradiated but allowed to continue their normal growth rate immediately following exposure to x-rays. There may be a certain amount of recovery going on during the period before growth is resumed.

After living material has been irradiated there is a certain amount of residual effect which continues at a steadily decreasing rate. According to KINGERY (**8**), the rate of decrease of this effect with time follows a logarithmic curve. If growth processes are delayed for a time, the amount of residual effect will be growing less and less in the meantime. Therefore, when the rate of metabolism is allowed to return to normal there will be less damage done to the cells which are again beginning to divide than would occur if they continued dividing immediately after the irradiation period. In like manner, the long, slow growth made possible by low temperature could be assumed to reduce radiation injury by allowing more time for the reduction of the amount of residual radiation.

PACKARD (**11**) performed a set of experiments on Drosophila eggs which very nearly parallel the tests reported here on growing corn seedlings at different temperatures following irradiation. After the same dose of x-rays, groups of eggs which were incubated at 18° C. hatched in 80 per cent. of the cases, while in the group kept at 28° C. only 53 per cent. hatched. Low temperatures after irradiation also reduced the amount of injury shown by chick embryos in experiments reported by ANCEL and VINTEMBERGER (**1**).

The fact that corn seedlings, Drosophila eggs, and chick embryos all react to temperature effects after irradiation in the same general way would seem to indicate that temperature during this period controls one or more fundamental conditions involved in determining the amount of irradiation injury shown by the living organism.

Summary

Seedlings of field corn were x-rayed with doses of 60 to 10,000 r and their subsequent growth observed under varying conditions. The results are as follows:

1. The height of the coleoptile was not affected by doses up to 5000 r which was the highest dose used in these particular experiments.

2. Shoots of plants which received over 800 r showed the effects of irradiation by delay in bursting through the coleoptile and by failure to reach the height attained by their controls during the time of the experiment.

3. All of the greenhouse plants irradiated with 200 r and more showed a chlorotic disturbance in the early leaves.

4. Leaves of all plants which received 800 r, and the small number of survivors from the 1200 r group, showed a strong tendency to curl their edges toward the under surface.

5. The rootlets growing laterally from the primary root were the most sensitive part of the seedlings. Doses of 75 r and higher delayed the appearance of these secondary roots increasingly as the dose was raised, while doses of 300 r and higher increased the distance between the grain and the first of these roots. Comparison of the time of appearance and spacing of these secondary roots is suggested as a method for comparing the degree of sensitivity to x-rays of various groups of seedlings.

6. Doses up to 10,000 r failed to prevent at least 20 mm. of root growth after radiation was applied.

7. Plants irradiated with doses between 800 and 2000 r showed a much shorter latent period before x-ray effects were measurable when grown at 36° C. after treatment than when grown at 24° C. and lower temperatures.

8. After a dose of 800 r corn seedlings showed the same amount of injury whether they were grown at 24° or 36° C. After 1500 r the 24° group grew faster than the 36° group after 50 hours, and the roots attained considerably greater length during their longer life. After doses of 2000 r the 24° groups surpassed the 36° groups after 35 hours and lived longer, but after this dose the final length was never more than 9 mm. greater than that of the 36° group. On the whole, lower temperatures after irradiation tended to reduce the amount of radiation injury.

The writer wishes to thank Professor William Seifriz for his interest and helpful criticism, Dr. Ellice McDonald for the use of the x-ray equipment and other laboratory facilities of the Biochemical Research Foundation of the Franklin Institute, and Professor Rodney H. True for the use of the greenhouses of the Department of Botany of the University of Pennsylvania.

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